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REPORT OF EVALUATION OF DECOMPRESSION SICKNESS, BEALE AFB 10-14 AUG 2009

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Convincing evidence of at least four very severe cases of central nervous system DCS and three cases of chokes. Several cases of probable and possible neurological and joint pain DCS cases. Cases are of a type and severity rarely found in flight operations. Appropriate treatment provided in the AOR. May be the direct result of increased physical activity in the cockpit and the longer (9-11 hours) altitude exposures. Signs and symptoms recur with a possible temporal relationship to the commercial flight home. Other factors undiscovered may also play a role; for example, homes are at a higher altitude than Beale AFB. Additionally, some subtle symptoms (i.e., fatigue) may be unrecognized and/or inadequately treated in theater prior to flight home. Symptoms persist for weeks, months, or longer and are very similar to traumatic brain injury symptoms. This may represent a "new" or previously unrecognized post-DCS syndrome.

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EXECUTIVE SUMMARY

Tasking:

A) Investigate recent severe decompression sickness (DCS) incidents occurring in U-2 pilots

B) Recommend potential risk mitigation strategies to decrease DCS incidents

Findings:

A) Convincing evidence of at least 4 very severe cases of central nervous system DCS and three cases of chokes

B) Several cases of probable and possible neurological and joint pain DCS cases

C) Cases are of a type and severity rarely found in flight operations

D) Appropriate treatment provided in the AOR

E) May be the direct result of increased physical activity in the cockpit and the longer (9-11 hours) altitude exposures

F) Signs and symptoms recur with a possible temporal relationship to the commercial flight home

   a. Other factors undiscovered may also play a role
   b. For example, homes are at higher altitude than Beale AFB
   c. Additionally, some subtle symptoms (i.e., fatigue) may be unrecognized and/or inadequately treated in theater prior to the flight home

G) Symptoms persist for weeks, months or longer and are very similar to traumatic brain injury symptoms

H) This may represent a "new" or previously unrecognized post-DCS syndrome

Possible Risk Mitigation Measures:

A) Use Exercise-enhanced pre-breathe

B) Reduce length of sorties

C) Increase rest cycle between sorties

D) Routinely fly with FPS partially inflated

    a. Altimeter for pressure suit needed

E) Reduce mission operating altitude

F) Decrease physical activity while at altitude

G) Maintain hydration

H) Maintain physical fitness

I) Maintain optimum body weight

TASKING

From 10 -13 Aug 2009, a team from Brooks City-Base representing the USAF School of Aerospace Medicine (USAFSAM), and 711 HPW/HPS visited Beale AFB at the request of the 9th Reconnaissance Wing Commander, BG Robert Otto, to investigate cases of severe decompression sickness (DCS) occurring in U-2 pilots and to suggest, if possible, strategies to mitigate the risk for developing DCS.

The team included Col Robert S Michaelson (Chief of Hyperbaric Medicine at USAFSAM), Dr. Andy Pilmanis (Consultant), and Dr. Tom Morgan (711 HPW/HPS).

BACKGROUND

The U-2 program has successfully operated for over 50 years. The combination of high altitude flight and prolonged exposures to altitude puts the U-2 pilot at risk for developing DCS. However, until recently, the relatively high incidence of DCS has been acceptable. In 1991 an anonymous survey of over 400 active and retired U-2 pilots was conducted by Dr. Pilmanis. His findings were:

A) Conclusion: DCS is more common than previously thought, and has caused significant mission impact at times

B) Results: 60%-80% of pilots report at least one case during career often unreported at the time of the incident. This was identified on an anonymous survey done in 1995.

   a. Of these 13% had neurological involvement
   b. 13-16% of these altered mission profile or returned early due to DCS
   c. Mission performance was affected by DCS in 34% of these
   d. Obstacle to reporting DCS: fear of grounding
   e. There was no evidence of long-term medical problems from DCS

Altitude research was carried out at the Air Force Research Laboratory under the direction of Dr. Pilmanis from 1989-2005. His research included:

A) 28 human-use protocols
B) 600+ subjects
C) All subjects were representative of the USAF rated aircrew population
D) 52% of the subjects had DCS at least once
E) 3000+ subject-exposures from 1983 to 2005
F) 38% of the subject-exposures had at least one DCS symptom
G) 36% of the subject-exposures with DCS had multiple symptoms

These data provides a robust database for comparison, allows predictive modeling, and identifies factors influencing the development of altitude associated DCS.

AVIATION DCS

In decompression sickness, the body is exposed to decreased ambient pressure as well as to decreased partial pressures of breathing gases. DCS occurs from the formation of bubbles in tissue or fluids in the body. Bubbles result from dissolved inert gas (nitrogen) that becomes supersaturated during decompression. Once a critical level of supersaturation is reached, the

inert gas comes out of solution to form bubbles. The amount of gas dissolved in body tissues follows Henry's law which states "the concentration of dissolved gas is equal to the Pressure on the system multiplied by the Solubility Coefficient of the gas (C= P x S)". Exposure to reduced ambient pressures, such as high altitude flight, or reduction in pressure after exposure to increased pressures such as scuba diving or caisson work are common mechanisms for the development of DCS. Under such reduced pressures, a "critical supersaturation" level is reached and nitrogen will not stay in its dissolved state but come out of solution in its gaseous state as bubbles. In DCS, bubbles can cause damage through either direct or indirect effects and include mechanical distortion of tissues, vascular obstruction, and/or stimulation of immune mechanisms. The symptoms of DCS can vary from mild to severe, ranging from vague constitutional symptoms to sudden loss of consciousness, death, or paralysis.

Multiple factors can influence the development of DCS. Among those studied include:

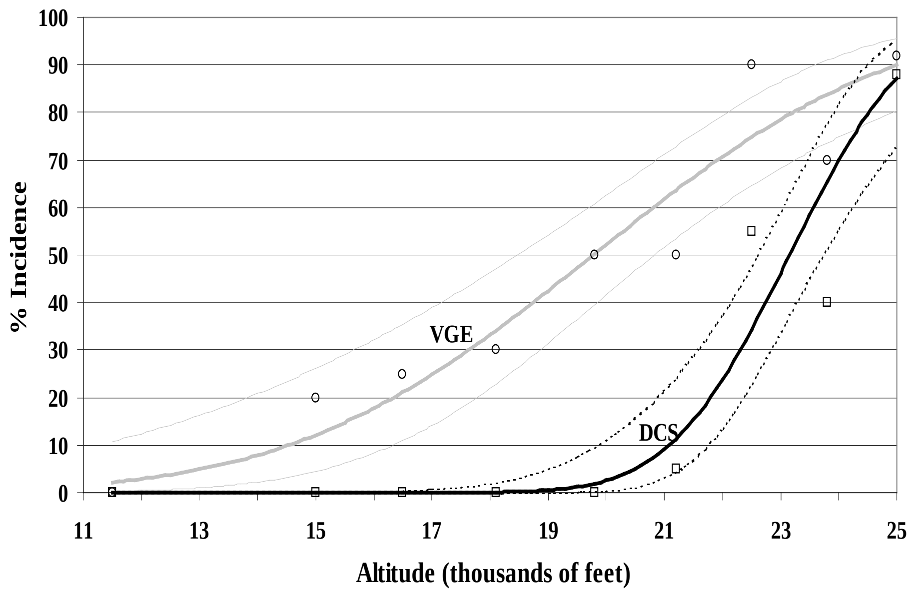
A) Altitude attained
B) Duration of exposure
C) Previous exposure to altitude
D) Oxygen prebreathing
E) Flying after diving
F) Age
G) Gender
H) Exercise at Altitude
I) Injury
J) Body build
K) Temperature
L) Hypoxia
M) Dehydration
N) Microgravity
O) Patent Foramen Ovale

Of those factors studied, the four below are the PRIMARY factors that influence the development of altitude decompression sickness:

A) Altitude attained
B) Duration of exposure
C) Exercise at Altitude
D) Oxygen prebreathe

The other factors examined above play a less significant and relatively minor role in development of DCS. However, given the significant physiological stress placed on U-2 pilots, even these minor factors play an important role in protecting aircrew from DCS and should not be ignored. We will concentrate on mitigation strategies related to the four major factors contributing to increased risk of DCS.

This chart demonstrates the effect of altitude attained and the risk of DCS (6 hour exposures, zero prebreathe, mild* exercise). The risk of DCS increases very rapidly once an altitude of FL 210 is reached. For background, please note that these are research subjects whose task was to report any symptom representing DCS.



(VGE is venous gas embolism. VGE's are bubbles identified in the venous blood system during altitude exposure. VGE is associated with development of DCS but is a separate entity.

FIGURE 1. Altitude Attained

***Less than 50% VO2 peak**

This chart demonstrates the effect time of exposure has on the development of DCS. The research subjects in this protocol mimicked the typical U-2 profile in that they were given a 30,000 ft altitude exposure after a 60 min prebreathe and conducted mild exercise while at altitude. The risk of DCS increases with longer time of exposure at altitude, particularly during the first two hours. In these subjects, there did not appear to be an increase in the risk of DCS after about four hours of exposure. However, in the U-2 cases we examined, this axiom did not hold true. Several severe cases that occurred during operational combat sorties did not demonstrate symptom onset until more than seven hours at altitude. This constitutes a new phenomenon that indicates risk continues to increase with longer duration at altitude.

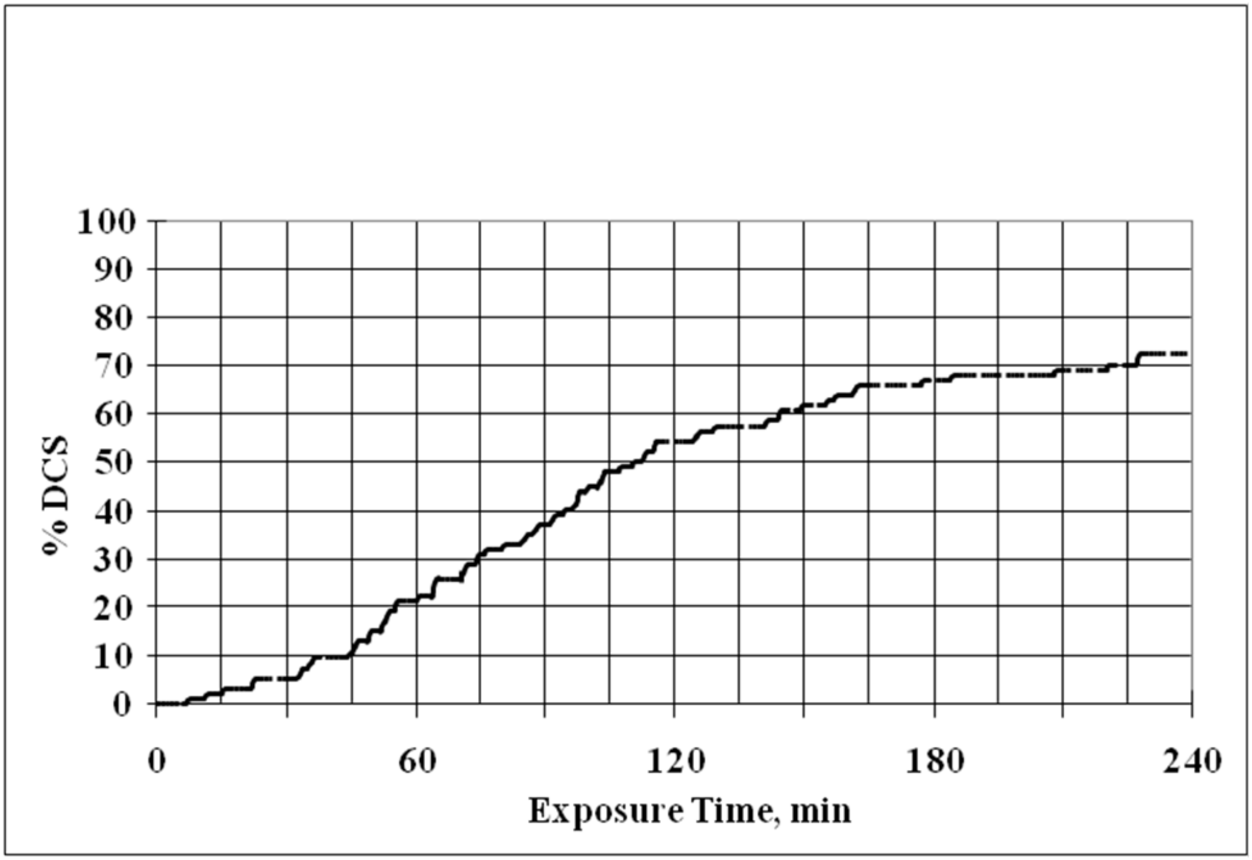


FIGURE 2. Time at Exposure

This chart shows the effect exercise at altitude has on the development of DCS (controls were DCS = 0%). Of note, isometric exercise (muscle pushing against muscle without movement,

such as pushing ones heels against the rudder pedals) incites DCS equivalent to isotonic (moving through a range of motion, such as raising ones arms to actuate flight instruments). This is important in the U-2 for two reasons. First, U-2 pilots are active in the cockpit, particularly compared to their predecessors who flew mainly strategic reconnaissance missions prior to the 1980's. Pilots flying U-2 missions today routinely interact with ground controllers with dynamic tasking and re-routing of their mission in response to real-time operations. Second, the stress levels routinely encountered by U-2 pilots during combat are significant. For example, as one pilot reported radio engagement with coalition ground forces was stressful enough to cause continued contraction of leg muscles and fatigue of the legs at the end of the mission.

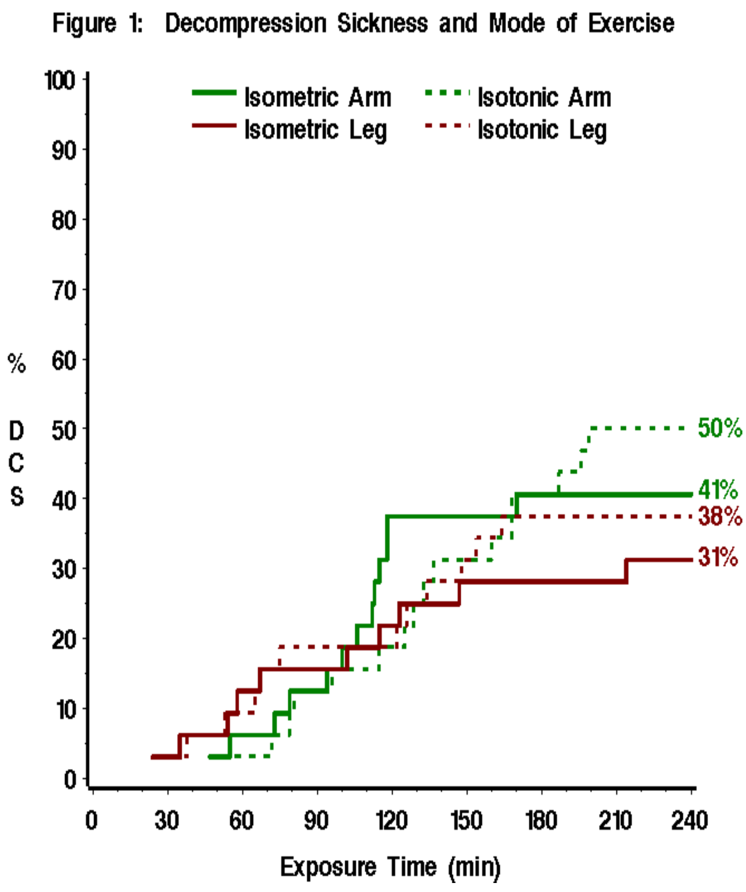
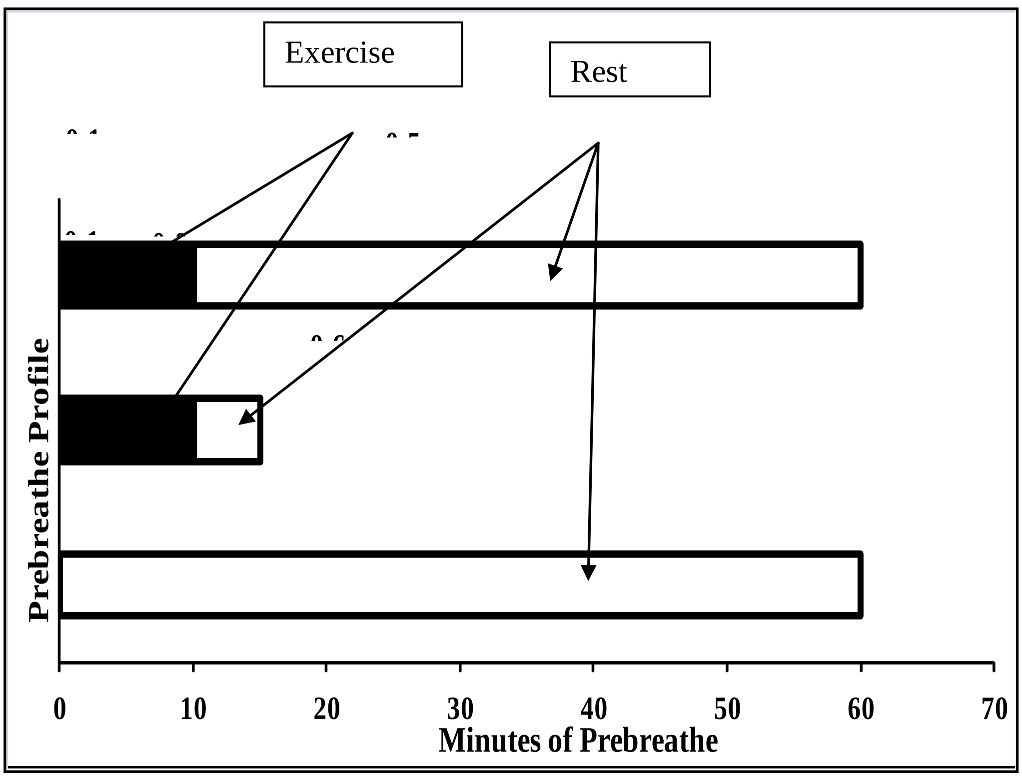


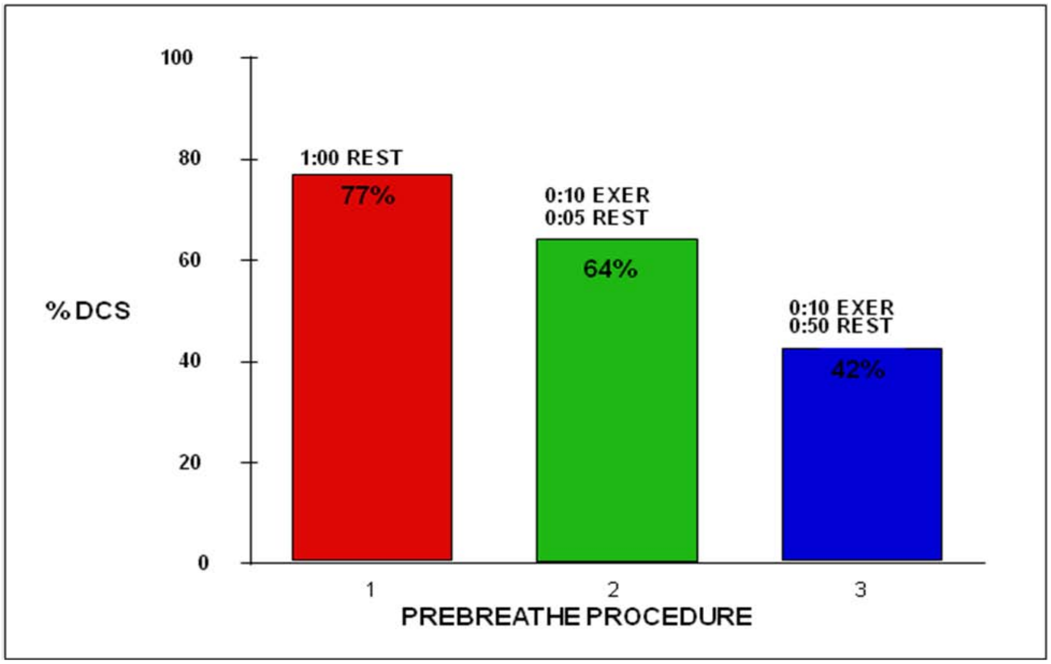
FIGURE 3. Exercise at Altitude

EXERCISE-ENHANCED PREBREATHE

The following charts show exercise enhanced pre-breathe (EEP) protocols studied at AFRL, the reduction of DCS risk in study subjects, and the equivalence of EEP in DCS risk reduction to four-hour resting oxygen pre-breathe.

This last chart demonstrates EEP using 10 minutes of exercise at 70% of peak oxygen consumption (VO2 peak) on 100% oxygen followed by a rest period of 50 minutes on 100% is equivalent in DCS risk reduction to four hours of 100% oxygen breathing at supine rest. Periods of exercise greater than 10 minutes do not provide significant reductions in DCS.





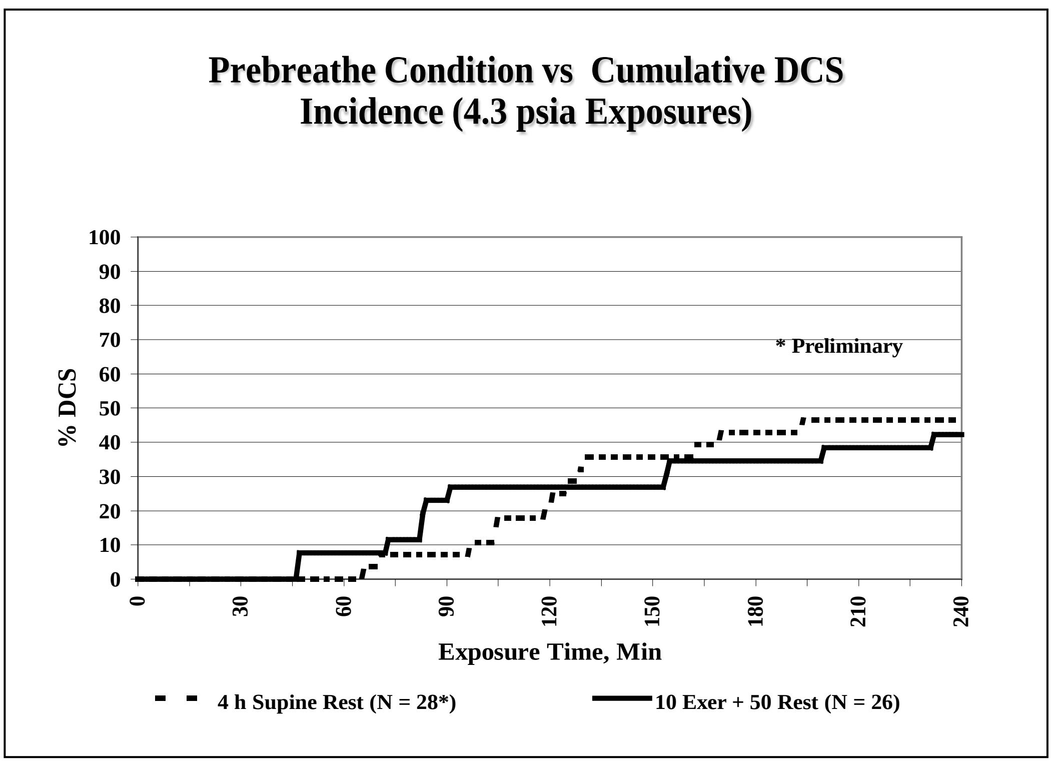


FIGURE 4. Exercise Enhanced Prebreathe

DCS CASES

To protect patient confidentiality, specific individual cases will not be described. However, we were able to talk to several pilots who had incidents during U-2 high flight and we wish to express our gratitude to those pilots. The following table illustrates the time course, symptoms, and operating locations of the subject DCS cases available to us at the time of our investigation.

Summary - Neurological DCS Cases

MP1	2002	Det 4	Severe CNS sx, sequelae x6+mo (HA, fatigue)
MP2	2003	Det 4	Worsening fatigue; resolved w/ HBOT
MP3	2002 2007	Det 1 Det 4	Mild personality changes, fatigue resolved ~8-12mo after incident. Persistent hyperacusis, subtle personality changes, irritability
MP4	2006	Det 4	Severe CNS symptoms, persistent long-term sequelae (HA, fatigue, personality changes). Radiological findings consistent with injuries.
MP5	2006 2007	Det 5 BAFB ? BAFB	- Knee pain resolved with surface level oxygen - Fatigue resolved after HBOT - L ulnar paresthesias x3mo, fasciculation persisted - Vertigo/tumbling, photophobia x3mo resolved
MP6	2006 2007	Det 5 Det 5	Feb 06 – HA, blurred vision (resolved w/SLO2) Aug 07 – fatigue, personality changes, chokes (resolved w/HBOT) but persistent long-term CNS symptoms
MP7	2007	Det 4	HA, nausea, dizziness; no long-term sequelae after HBOT
MP8	2007	BAFB	Moderate CNS sx initially, persistent severe long-term sequelae (HA, fatigue)
MP9	2006 2008	BAFB Det 4	- LUE paresthesia, L elbow pain; no sequelae after HBOT - Severe CNS sx, no sequelae after HBOT
MP10	2009	Det 4	Severe CNS sx, sequelae (HA, fatigue resolved after 2nd HBOT & 4mo rest)
MP11	2009	Det 4	Severe CNS sx, sx recurred & improved after 2nd HBOT; persistent fogginess, flashbacks, irritability, personality change
MP12	2009	Det 4	Peripheral neuropathy & joint pain only; resolved with HBOT
MP13	2009	Det 4	HA & fatigue; no sequelae (?) after HBOT

MP = Mission Pilot
HBOT = Hyperbaric Oxygen Treatment
CNS = Central Nervous System
HA = headache
BAFB = Beale AFB

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Figure 5. Summary Neurologic DCS Cases

FINDINGS

A) Convincing evidence - at least four very severe cases of central nervous system DCS and three cases of chokes

B) Several cases of probable and possible CNS DCS

C) Cases are of a type and severity with symptoms not documented previously in the U-2 community

D) Most occurred at one location

E) Severe cases associated with increased OPS TEMPO, specifically, longer flights, increased physical activity at altitude, and increased fatigue

F) Appropriate treatment was administered in the theater medical facilities

G) Majority of cases occurred in a small number of pilots

H) Cabin altitudes varied between 27,000 and 29,000 ft

I) Signs and symptoms recurred with a possible temporal relationship to the commercial flight home and responded to repeat hyperbaric oxygen treatment at home station

J) Other factors undiscovered may also play a role

K) Homes are at higher altitude than Beale AFB - in some cases recurrence seems to have occurred after returning to their home at the higher altitude

L) Symptoms persist for weeks, months and in some cases years. The symptoms are very similar to what has been reported in chronic mild and moderate traumatic brain injury and include sleep disturbances, short term memory difficulties, uncharacteristic irritability, and noticeable personality changes. This may represent a new or previously unreported post-DCS syndrome

M) One pilot had objective findings showed on MRI lesions in areas of the brain corresponding to the lasting manifestations

FINDINGS CONSIDERED NOT TO BE ASSOCIATED WITH DCS

A) No correlation of DCS incidents to aircraft tail number

B) Adequate integration & pre-launch protocols with no breaks or changes that could cause DCS

C) Oxygen system and LOX supplies checked out as functioning normally and non-contaminated, respectively

   a. No mechanism to allow contaminate into O2 system while flying unless catastrophic failure

D) Treatment chamber in theater uses state-of-the-art equipment with appropriately trained staff

E) No environmental exposures unique to ADAB (i.e., no identified endemic disease, chemical exposures, etc.)

F) No correlation of DCS incidents to GelDex use (in fact, the vast majority of incidents occurred when no GelDex was used)

G) No underlying medical issues or acute illnesses among the affected pilots

POTENTIAL RISK MITIGATION STRATEGIES

Mitigation of DCS risk in the U-2 requires an in-depth understanding of the U-2 flight profile and the physiological factors that predispose aircrew to altitude DCS. From a physiological standpoint, the standard U-2 high-altitude mission constitutes a high risk mission. Data from altitude chamber subjects cited previously predict an almost 75% risk of developing DCS in any high flight U-2 mission lasting four hours or more. These same human performance studies performed between 1989-2005 shows that the four most important factors contributing to DCS susceptibility are pre-breathe, altitude achieved, time at altitude, and exercise at altitude. In this sense, U-2 pilots are operating at the limits of both human and aircraft performance. Their standard mission entails flight over 60,000 feet for 10 hours or more while performing frequent movements in the cockpit to perform payload adjustments and/or interact with ground controllers. Aircrew in other platforms may approach or exceed this level of risk at times, such as a high-altitude parachute drop from the CV-22 Osprey.

DCS Symptom Incidence (%) in Research Subjects Exposed to Altitude Profiles Similar to These Operational Scenarios

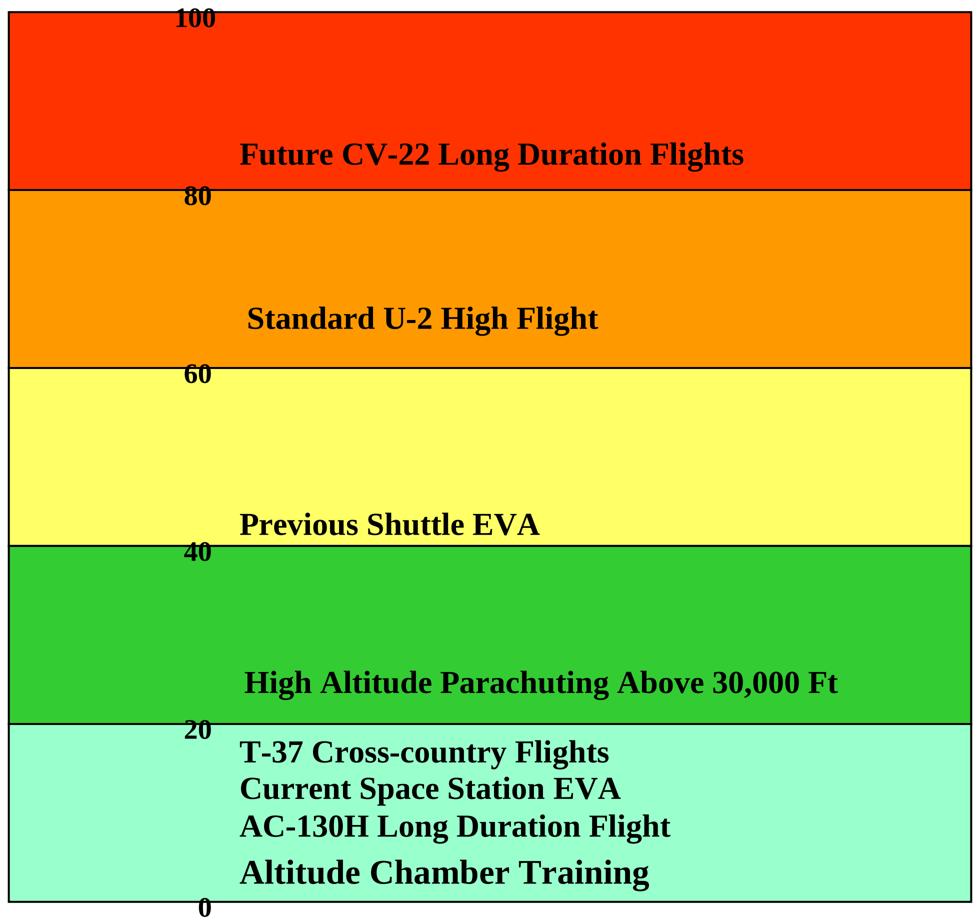

FIGURE 6. DCS Symptom Incidence

However, U-2 pilots deploy for two-month periods multiple times per year and they fly missions every fourth day. Moreover, the program has sustained and improved upon this level of operation since 2002. This sustained high risk altitude exposure is unique and unprecedented in modern aviation.

We recognize that the same factors most important to decreasing the risk of DCS are also the most important operational considerations in mission preparation and mission accomplishment. Other factors such as diet, rest/sleep cycles and good physical condition must be maximized and may reduce some risk. However, modifications in time at altitude, altitude achieved, amount of exercise at altitude, and prebreathing will need to be modulated to reduce the risk of DCS. As stated above, the U-2 mission is a high risk mission. Data from altitude chamber subjects predict an almost 75% risk of developing DCS in any high flight U-2 mission lasting around four hours. Again, this is data derived from subjects for whom DCS was induced intentionally and the subjects reported every possible symptom of DCS. These data do not correlate directly to U-2 operational sorties, but survey data did show about 60-80% of active and retired U-2 pilots had at least one episode of DCS during their career and 1/3 reported DCS had direct mission impact. We believe the numbers are probably under-reported and the true number of pilots having some level of DCS is higher.

Achieving any significant degree of DCS risk mitigation in the U-2 requires attacking the four risk factors proven in human performance studies to be most critical for susceptibility to altitude DCS: pre-breathe, altitude achieved, time at altitude, and amount of exercise at altitude. From an operational standpoint, altering parameters such as flight altitude may seem inconceivable at first glance. After all, the purpose of the U-2 is to fly at high altitude. However, human research studies demonstrate that even seemingly minor modifications (e.g., flying with the pressure suit partially inflated) should significantly reduce DCS risk. Moreover, these alterations should be easily achievable with minimal effort for most missions. The following paragraphs will discuss the cost-benefit trade-offs and justification for potential operational risk management strategies in detail.

1. The single most effective DCS countermeasure is the use of exercise-enhanced prebreathing (EEP). It involves just 10 min of exercise within a 60 min prebreathe. It is available, it is inexpensive, no additional time is required, and it reduces DCS risk by about 40%. It is recommended that ANY PILOT that develops ANY DCS symptoms during ANY FLIGHT should use EEP for all future flights. Simply increasing the duration of resting prebreathe only

decreases the DCS risk by about 10% for each additional hour after the first hour compared to about 40% with EEP of 60 min with 10 min of exercise.

. 2. Reduction in sortie length may also significantly reduce risk. The data indicates that most of the severe CNS cases resulted from 9 to 11 hour missions. Such very long missions combined with increased physical activity by the pilot could alone explain the increased incidence of severe CNS cases.

3. In addition, we believe additional effective mitigation strategies and reduction of DCS can be achieved if parts of the ORM pre-flight included evaluation of altitude required for mission completion and suit pressure used during the mission. In most operations, the cabin altitude during a high flight mission is around FL290. If during mission pre-flight, it is determined that mission threat is low and the aircraft can be flown at a lower altitude, and suit pressure can be maintained at some psi above 0, DCS risk can be significantly reduced. We recognize some missions will be a "must go" at high altitude and with workloads not permitting increase in suit pressure and no significant risk reduction can be achieved. These are operational considerations. We suggest evaluating risk tolerance for each mission.

Dr. Pilmanis' group at the Air Force Research Laboratory (AFRL) developed an altitude DCS risk prediction calculator (ADRAC, Altitude Decompression Sickness Risk Assessment Calculator) based on data obtained from altitude chamber subjects over the course of 20 years of research at Brooks AFB. The predictions are population-based and cannot be applied to an individual, except as part of a population. In other words, if the prediction is 20% DCS for a specific exposure profile, it means that if you placed 100 individuals in the chamber and exposed them to that specific profile, 20 of them are expected to develop one or more of the symptoms of DCS. **It does not mean** that if you placed one individual in the chamber for that profile that **he/she** has a 20% chance of getting DCS.

The three tables below provide the calculated estimates on DCS risk for combinations of cabin altitude and suit pressure. It must be clear that these are predictions based on altitude chamber research conducted under controlled conditions. U-2 missions include many additional variables

that may not be accountable in these predictions. Nevertheless, an attempt was made to account for a few of the variables that are believed to be involved in the recent increase in severe CNS DCS. From the research, it was found that a 60 min EEP was roughly equivalent to a 4 hour resting prebreathe (column D). Due to the increase in physical activity in the cockpit during recent missions, MILD exercise was changed to HEAVY exercise in the predictions (columns C and D). There is no data available to account for the very long exposure times, the increased stress, and increased fatigue. Therefore, they cannot be used with ADRAC predictions. However, it is reasonable to assume that these factors would increase the DCS risk above the numbers in Column C and D. It is clear from predictions in B, C, and D that there is a dramatic drop in DCS risk below a physiological altitude of 24,000 ft. Thus, the aim of the combination of suit inflation and cabin altitude should also be to end up below 24,000 ft.

Table 1: Physiological altitude (ft) vs %DCS risk

A	B	C	D
30,000	74	88	65
28,000	52	76	32
26,000	45	71	27
24,000	34	54	18
22,000	5	5	1

A Physiological altitude, i.e. the altitude the pilot's body is exposed to inside the suit

B Standard U-2 exposure profile: 60 min of resting prebreathe and mild exercise at altitude

C Recent U-2 exposure profile: 60 min of resting prebreathe, more exercise at altitude, longer exposure times at max altitude, more stress and fatigue

D Recent U-2 exposure profile with addition of EEP

Table 2 defines the physiological altitude resulting from a combination of cabin altitude reduction (flying lower) and various levels of suit inflation **DURING THE WHOLE MISSION**. It must be emphasized that, unlike the current/past practice of inflating the suit

when symptoms occur (attempted treatment); this proposed practice of suit inflation is during the entire time at altitude (prevention). Again, the objective is to reduce the physiological altitude (the altitude the pilot's body sees) to below 24,000 ft.

Table 2: Physiological altitude from suit inflation plus cabin altitude

Cabin Altitude (ft)	Suit Inflation (psi)			
	0.5	1.0	1.5	2.0
30,000	27,500	25,500	23,500	21,500
29,000	26,500	24,500	22,500	20,500
28,000	25,500	23,500	21,500	19,500
27,000	25,000	23,000	21,000	19,000
26,000	24,000	22,000	20,000	18,000
25,000	23,000	21,000	19,000	17,000

Table 3 summarizes the suggested suit inflation schedule as determined by the cabin altitude in order to reduce the DCS risk to levels of 15 to 30%. In comparison, NASA uses 15% for extra-vehicular missions and ACC uses 20% for F/A-22 missions. These are estimates, but are significantly lower than the 60 to 90% DCS risk prediction numbers for current operations. Only one piece of equipment will be needed to implement this suit inflation schedule. A pressure gage must be installed in the suit so the pilot can adjust the suit pressure as prescribed.

Table 3: Summary of suggested suit inflation

Cabin altitude (ft)	**suit inflation (psi)**
29,000-30,000	**2.0**
27,000-29,000	**1.5**
25,000-27,000	**1.0**
25,000 or below	**0.5**

MEDICAL RECOMMENDATIONS

Below is a list of treatment recommendations based on our visit to Beale AFB. The recommendations are empiric and based solely on expert opinion. There is no scientific literature available to reference since these cases of neurological DCS are truly unique in aviation medicine. The USN Dive Manual Revision 6 was consulted for the treatment table extension. If the recurrence of neurological signs and symptoms is related to the relative hypoxia experienced in commercial aviation, intuitively it makes sense to offer oxygen on the flight home to remove this as a potential risk factor.

A) Change initial hyperbaric treatment for neurological DCS to full extensions at 60 feet-sea water
B) Return home from theater on supplemental oxygen
C) Establish protocol for post-DCS neuro eval, i.e., neuropsychological testing (baseline & post-incident)
D) Consider Functional MRI with diffusion tensor mapping
E) Establish a standing DCS Working Group at Beale AFB for continuous evaluation & refinement of practices. We would welcome the opportunity to be members.
F) Develop better data collection & targeted research
G) Formalize data collection at Flight Surgeon's Office
H) Formation of an expert panel to develop clinical guidelines for central nervous system DCS treatment. We are currently asking for funding from the AF/SG office to form such a panel which will include aviation and diving DCS expertise. Support will be solicited from the Aerospace Medical Association and the Undersea and Hyperbaric Medicine Society.

CONCLUSIONS

Several cases of very severe neurological decompression sickness cases occurred among U-2 pilots since 2002, correlating with the increased operating tempo experienced by the squadron associated with combat in the Southwest Asia area of operations. These cases are of a severity not documented previously in the U-2 program, and are of a nature both life and aircraft threatening. The cases also occurred outside of parameters of our collective experience and current state of research. Specifically, many of the incidents occurred late in the missions, well after the point where research indicated that risk should have stabilized. Additionally, some cases have recurrence of signs and symptoms days to weeks after the initial event and have responded to repeat hyperbaric oxygen therapy. Finally, several case pilots complained of long-term neurological effects that had not been reported before. Neuropsychiatric symptoms such as memory problems, sleep disturbance, irritability, and personality change persist in some of the pilots. For a few cases, symptoms persist for years and may represent permanent neurological injury. This is certain in at least one case as demonstrated by objective MRI scans.

Effective mitigation requires addressing the major factors proven to constitute the vast majority of altitude DCS: decrease in cabin altitude, decreased time of exposure, exercise-enhanced prebreathe, and suit inflation during the whole mission. We recognize these are operational considerations. Still, even relatively small variations in these parameters offer significant opportunities for risk reduction and typical operations offer significant flexibility in these parameters. To that end, we have provided several tools to help modulate these parameters without compromising mission completion. We recognize mission requirements will dictate risk tolerance and there may be times when operations demand acceptance of greater risk to the pilots. To help balance this perspective, consider that the frequency and severity of DCS cases encountered by U-2 pilots since 2002 suggest operations are approaching the boundary of human

performance. From an aviation safety standpoint, some of the severe cases could have ended in the loss of both the aircraft and pilot lives. As it stands, the U-2 program has lost the services of at least 13 pilots for certain, and probably more that were unreported. In most cases, these losses were permanent. Five of the thirteen pilots considered in our case series returned to active flying duty in the U-2. One is in the process of requalifying now while three others moved to command and staff billets in order to limit their flying duties due to the perceived risk of recurrent DCS. We are unable to quantify the impact of these types of losses on the U-2 community. We are also grappling with the aeromedical implications involved with treating pilots and returning them to fly again after suffering neurological DCS.

What remains inexplicable is the physiological basis for the severe nature of the DCS cases reported in these U-2 pilots. This has not been encountered previously nor reported in the aviation literature. Severe DCS with permanent neurological dysfunction is relatively common in the diving community, but extremely rare in the aviation community. The apparent permanent nature and manifestations mimicking chronic brain injury are also novel. We cannot readily explain this phenomenon. It may represent a new form of post-DCS syndrome.

Theoretically, cerebral edema may occur secondary to nitrogen bubbles in the brain. Since HBO reduces cerebral edema, the aggressive hyperbaric treatments are therapeutic for both bubble reduction and cerebral edema. However, in these severe CNS cases, the edema may return after HBO treatment, which could appear as recurrence of symptoms. Follow-on HBO treatments may be beneficial in reducing unresolved cerebral edema. Therefore, when severe CNS DCS occurs, we advise treating the patients initially with a maximally extended US Navy Treatment Table 6 hyperbaric oxygen schedule.

Traumatic brain injury is a process that results in both structural and biochemical damage to neurons. In a similar fashion, DCS and resultant cerebral edema may disrupt the normal physiological function of neurons. Disrupted neurons from DCS/edema may be “marginal” and be on the edge of being active/inactive. Therefore, any minor influence could disrupt their function. For example, cabin altitudes of 6-8,000 feet while flying home may cause enough hypoxia to put some neurons back to sleep where normally such low levels of hypoxia are

tolerated with no difficulty. This may explain why some pilots have experienced recurrent symptoms while flying home from theater operations or while driving to their homes located at higher altitudes than Beale or Travis AFB.

When a recurrence of symptoms happens and is treated with additional HBO, some damaged neurons may be reactivated and symptoms improve. However, some neurons may not be activated or may be permanently damaged and may account for the longer lasting symptoms. When the ischemic neural damage is mild to moderate in severity, the patient is unlikely to have any noticeable changes that would be evident on radiological studies (i.e., CT scan, MRI, or X-Rays) or gross neurological exam. Consequently, the patient is likely to appear well clinically but still have subtle defects in mental function that become apparent with more focused clinical neurological and psychological exams. These patients are likely to experience subtle symptoms for several weeks to months following their initial DCS incidents. However, they appear to eventually clear gradually over time. We believe these pilots would probably benefit from a more aggressive risk management strategy in order to protect them from the high likelihood of recurrence in the future. In only one case among the incidents we studied was the ischemic neural damage from the pilot's DCS incident so severe that he had evidence of structural damage apparent on multiple MRI scans of his brain. In this case, the patient has permanent clinical neurological and psychological deficits that prevent him from ever flying again.

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